Development of a Laser Line Scan LIDAR Imaging System for AUV Use

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LONG-TERM GOALS

Our overall goal is to develop a "next generation" underwater optical imaging system for deployment on an Autonomous Underwater Vehicle. The system is predicted to have extended range performance (> 3 total attenuation lengths).

OBJECTIVES

This project is an extension of work that was initiated after the successful outcome of SBIR Phase I and II programs that demonstrated that a new type of fiber laser could be developed that would fulfill the necessary role in a "next generation" underwater Laser Line Scan System for deployment on an AUV. Here, funds have been allocated to build two underwater "pods" that are suitable for inclusion deployment on Autonomous Underwater Vehicles.

APPROACH

One of the most difficult imaging situations is when looking through turbid media. Motivated by the many applications that occur in medical, environmental, and the military, there has been a prevailing need for either formulating better imaging geometries or understanding the limitations of the existing ones.

The achievable resolution in turbid media is typically limited by the severe scattering that photons are subject to when transiting back after reflection from a target of interest. This is in contrast with many areas such as optical microscopy and semiconductor wafer inspection, where more often than not, resolution is imposed by the diffraction limit.

The most conventional and oldest method of forming images is when a subject is illuminated by a light source with a broad beam pattern. The light reflected from the target can then be "imaged" by some type of camera system. Under the assumption that the observed resolution is limited by the point spread function (psf) of the medium, a simplifying assumption represents the observed image, I(x',y') as a convolution of the medium psf with the reflectance map, ❐(x,y) so that I(x',y') = psf(x,y) ⊗ ❐(x,y) (⊗ is the convolution operator). Equivalently, the observed image can be represented as

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$I(x',y') = \int I(x,y)\, psf(x'-x, y'-y)dxdy$. The linear systems theory that describes this process has been extensively covered in standard texts.

One common goal in imaging research has been to increase spatial resolution. This has been pursued in both hardware through the design of sophisticated systems, and also in software through the use of signal processing algorithms. As one option, common in microscopy, the use of a scanning source and receiver can present substantial advantages over non-scanning systems. So, for example, in the case of confocal optical imaging, the observable diffraction-limited point spread function is the square of the more traditional, non-confocal point spread function. This leads to increased image resolution via a narrowing of the overall system point spread function.

Under almost all circumstances, underwater viewing is limited due to the turbidity of the environment. The effect of the suspended water, particles, and organisms is to both attenuate and scatter light. The ranges at which informative images can be obtained vary greatly. In practice, under the most ideal situations, ranges of less than a hundred meters are possible. A complicating factor is the severe backscatter, or volume scatter, which creates a large veiling glow that shrouds image contrast. Practical solutions in order to circumvent this effect concern the use of either large camera light separation, scanned, or pulsed systems.

The latest generation of underwater optical imaging systems are not limited by this backscatter effect and are constrained more by the spatial low pass nature of the forward scatter of light as it travels to the camera after reflection from the target. One class of underwater imaging systems that has shown good performance is known as the Laser Line Scan Systems. These systems have been developed over the last decade and have been used primarily to image the sea floor and objects on it.

Here, we describe work accomplished during the period October 1, 20010 – August 31, 2011. During this period, the project has progressed as we (Lockheed Martin Aculight, LMA, and SIO) have designed, built, and tested the hardware optical and electronic components for the final system. System tests by LMA have confirmed that the performance of the final configuration optical components will meet system specification goals. SIO supervised the assembly and delivery to LMA of the system chassis. Work with the Metron Corporation has also been collaboratively progressing as they have been working towards the creation of a model to predict system performance.

As a result of choice of the Hydroid Remus 600 vehicle for our deployment platform and have been working with Hydroid to prescribe both the system's package and its incorporation into the Hydroid Remus 600 vehicle. This information has been incorporated into our expansion proposal to integrate the system into the Hydroid vehicle. We categorize our planned work as Phase III of a three-phase development. The jointly developed end product from Phase II is a laser imager that SIO will integrate into the Hydroid Remus 600 Vehicle AUV for at-sea testing.

1. **Phase I** was the development of a prototype imager for tank testing and proof of concept and was funded via a Phase I and II SBIR.
2. **Phase II** is the engineering effort to repackage the imager to fit into a 12.75" diameter AUV (funded under N00014-09-1-0477).
3. **Phase III** is the planned future development to perform tank tests, tow tests, and to integrate the laser imager into the AUV and to conduct at-sea testing.

During Phase I (funded as N00014-06-C0083 SBIR Phase II), LMA and SIO worked together (with LMA as prime and SIO as sub) to develop a brass board laser transmitter and a receiver with a FOV of ~5 degrees. Phase II work that was performed resulted in a system with a wider FOV and faster scan rate within a compact, watertight pressure vessel for all tests. The Phase II prototype was delivered to SIO in July, 2011 and is now configured with data acquisition software as well as a cusom fabricated test tank. Figure 2 shows the system in Dr. Jaffe's lab, undergoing tests, and Figure 3 shows the test tank configuration that will permit the extended range imaging performance to be tested.

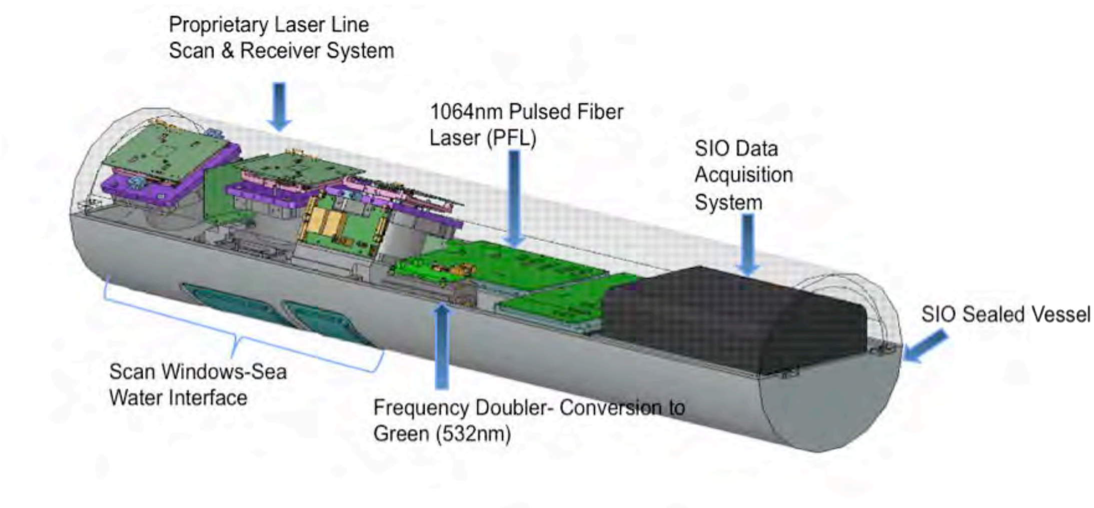

Figure 1: Prototype underwater imaging system representing the Phase II deliverable

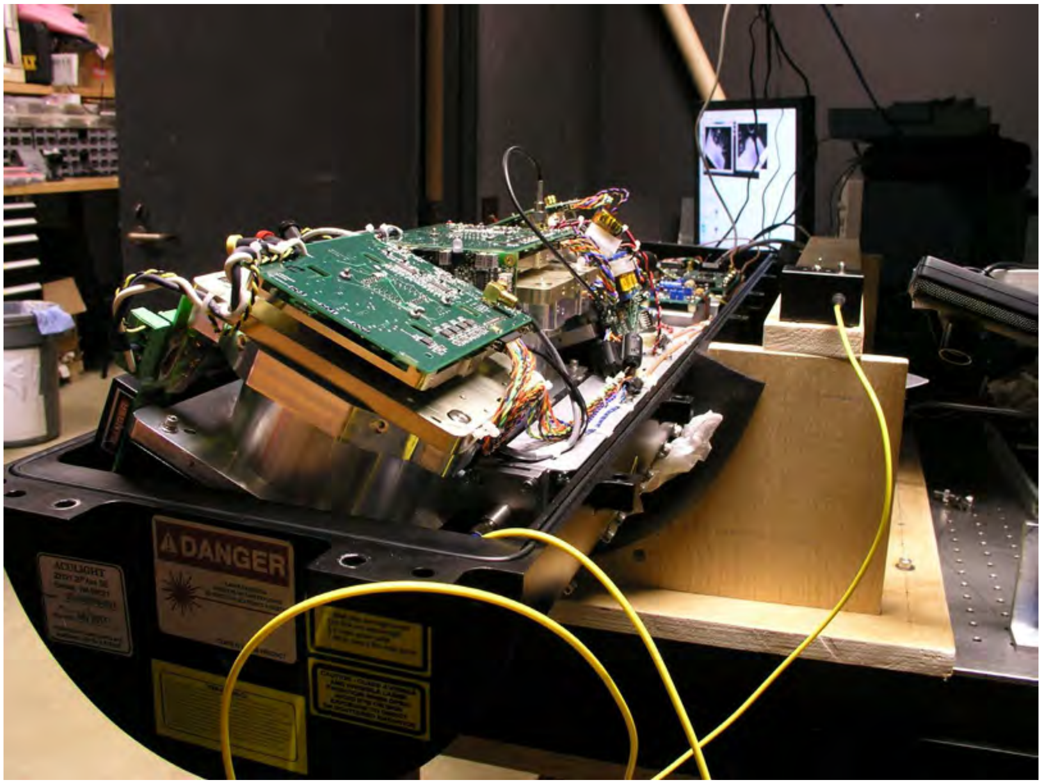

Figure 2: The prototype system in Dr. Jaffe's lab

Figure 3: The test tank facility in Dr. Jaffe's lab. The tank can accommodate the range of intended imaging distances of 5 – 15 meters.

We note that the bulk of work done during this period was that of LMA where considerable resources were spent in getting the signal to noise level high, the pulse duration low, and the decay constant for the receive circuitry decay at a fast enough rate to permit the imaging of targets that are close to the system. We also note that all of the electro-optical components, such as the custom lenses and the curved windows were tested and found to perform well within the specifications.

IMPACT/APPLICATIONS

The system has direct implications for incorporation in the present generation of Autonomous Underwater Vehicles. Such vehicles are routinely used for mine identification in littoral waters. Our system will offer increased range and resolution imaging in a portable package, suitable for Navy deployment.